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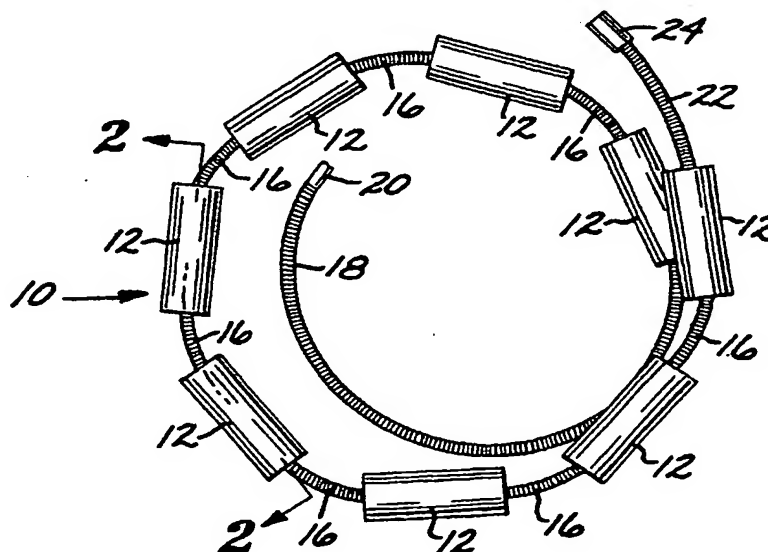
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(54) Title: FILAMENTOUS EMBOLIC DEVICE WITH EXPANSIBLE ELEMENTS



(57) Abstract: An embolization device includes a plurality of highly-expandible embolizing elements disposed at spaced intervals along a filamentous carrier. In a preferred embodiment, the carrier is a suitable length of very thin, highly flexible filament of nickel/titanium alloy. The embolizing elements are separated from each other on the carrier by radiopaque spacers in the form of highly flexible microcoils made of platinum or platinum/tungsten alloy. In a preferred embodiment, the embolizing elements are made of a hydrophilic, macroporous, polymeric, hydrogen foam material. The device is particularly suited for embolizing a vascular site such as an aneurysm. The embolization bodies have an initial configuration in the form of small, substantially cylindrical "micropellets" of small enough outside diameter to fit within a microcatheter. The bodies are hydrophilically expandable into an expanded configuration in which they substantially conform to and fill the vascular site while connected to the carrier.

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FILAMENTOUS EMBOLIC DEVICE WITH
EXPANSIBLE ELEMENTS

CROSS REFERENCE TO RELATED APPLICATION

This application is a Continuation-in-Part of co-pending
application Serial No. 09/410,970, filed October 4, 1999.

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable

BACKGROUND OF THE INVENTION

The present invention relates to the field of methods and devices
for the embolization of vascular aneurysms and similar vascular
abnormalities. More specifically, the present invention relates to an
embolic device that is inserted into a vascular site such as an aneurysm to
create an embolism therein and a method for embolizing a vascular site
using the device.

The embolization of blood vessels is desired in a number of clinical
situations. For example, vascular embolization has been used to control
vascular bleeding, to occlude the blood supply to tumors, and to occlude
vascular aneurysms, particularly intracranial aneurysms. In recent years,
vascular embolization for the treatment of aneurysms has received much
attention. Several different treatment modalities have been employed in
the prior art. U.S. Patent No. 4,819,637 - Dormandy, Jr. et al., for
example, describes a vascular embolization system that employs a
detachable balloon delivered to the aneurysm site by an intravascular
catheter. The balloon is carried into the aneurysm at the tip of the
catheter, and it is inflated inside the aneurysm with a solidifying fluid
(typically a polymerizable resin or gel) to occlude the aneurysm. The

1 balloon is then detached from the catheter by gentle traction on the
2 catheter. While the balloon-type embolization device can provide an
3 effective occlusion of many types of aneurysms, it is difficult to retrieve or
4 move after the solidifying fluid sets, and it is difficult to visualize unless it
5 is filled with a contrast material. Furthermore, there are risks of balloon
6 rupture during inflation and of premature detachment of the balloon from
7 the catheter.

8 Another approach is the direct injection of a liquid polymer
9 embolic agent into the vascular site to be occluded. One type of liquid
10 polymer used in the direct injection technique is a rapidly polymerizing
11 liquid, such as a cyanoacrylate resin, particularly isobutyl cyanoacrylate,
12 that is delivered to the target site as a liquid, and then is polymerized *in*
13 *situ*. Alternatively, a liquid polymer that is precipitated at the target site
14 from a carrier solution has been used. An example of this type of embolic
15 agent is a cellulose acetate polymer mixed with bismuth trioxide and
16 dissolved in dimethyl sulfoxide (DMSO). Another type is ethylene vinyl
17 alcohol dissolved in DMSO. On contact with blood, the DMSO diffuses
18 out, and the polymer precipitates out and rapidly hardens into an embolic
19 mass that conforms to the shape of the aneurysm. Other examples of
20 materials used in this "direct injection" method are disclosed in the
21 following U.S. Patents: 4,551,132 - Pásztor et al.; 4,795,741 - Leshchiner
22 et al.; 5,525,334 - Ito et al.; and 5,580,568 - Greff et al.

23 The direct injection of liquid polymer embolic agents has proven
24 difficult in practice. For example, migration of the polymeric material
25 from the aneurysm and into the adjacent blood vessel has presented a
26 problem. In addition, visualization of the embolization material requires
27 that a contrasting agent be mixed with it, and selecting embolization
28 materials and contrasting agents that are mutually compatible may result
29 in performance compromises that are less than optimal. Furthermore,

1 precise control of the deployment of the polymeric embolization material
2 is difficult, leading to the risk of improper placement and/or premature
3 solidification of the material. Moreover, once the embolization material
4 is deployed and solidified, it is difficult to move or retrieve.

5 Another approach that has shown promise is the use of
6 thrombogenic microcoils. These microcoils may be made of a
7 biocompatible metal alloy (typically platinum and tungsten) or a suitable
8 polymer. If made of metal, the coil may be provided with Dacron fibers
9 to increase thrombogenicity. The coil is deployed through a
10 microcatheter to the vascular site. Examples of microcoils are disclosed
11 in the following U.S. patents: 4,994,069 - Ritchart et al.; 5,133,731 -
12 Butler et al.; 5,226,911 - Chee et al.; 5,312,415 - Palermo; 5,382,259 -
13 Phelps et al.; 5,382,260 - Dormandy, Jr. et al.; 5,476,472 - Dormandy, Jr.
14 et al.; 5,578,074 - Mirigian; 5,582,619 - Ken; 5,624,461 - Mariant;
15 5,645,558 - Horton; 5,658,308 - Snyder; and 5,718,711 - Berenstein et al.

16 The microcoil approach has met with some success in treating
17 small aneurysms with narrow necks, but the coil must be tightly packed
18 into the aneurysm to avoid shifting that can lead to recanalization.
19 Microcoils have been less successful in the treatment of larger aneurysms,
20 especially those with relatively wide necks. A disadvantage of microcoils
21 is that they are not easily retrievable; if a coil migrates out of the
22 aneurysm, a second procedure to retrieve it and move it back into place is
23 necessary. Furthermore, complete packing of an aneurysm using
24 microcoils can be difficult to achieve in practice.

25 A specific type of microcoil that has achieved a measure of success
26 is the Guglielmi Detachable Coil ("GDC"), described in U.S. Patent No.
27 5,122,136 - Guglielmi et al. The GDC employs a platinum wire coil fixed
28 to a stainless steel delivery wire by a solder connection. After the coil is
29 placed inside an aneurysm, an electrical current is applied to the delivery

1 wire, which heats sufficiently to melt the solder junction, thereby
2 detaching the coil from the delivery wire. The application of the current
3 also creates a positive electrical charge on the coil, which attracts
4 negatively-charged blood cells, platelets, and fibrinogen, thereby
5 increasing the thrombogenicity of the coil. Several coils of different
6 diameters and lengths can be packed into an aneurysm until the aneurysm
7 is completely filled. The coils thus create and hold a thrombus within the
8 aneurysm, inhibiting its displacement and its fragmentation.

9 The advantages of the GDC procedure are the ability to withdraw
10 and relocate the coil if it migrates from its desired location, and the
11 enhanced ability to promote the formation of a stable thrombus within the
12 aneurysm. Nevertheless, as in conventional microcoil techniques, the
13 successful use of the GDC procedure has been substantially limited to
14 small aneurysms with narrow necks.

15 Still another approach to the embolization of an abnormal vascular
16 site is the injection into the site of a biocompatible hydrogel, such as poly
17 (2-hydroxyethyl methacrylate) ("pHEMA" or "PHEMA"); or a polyvinyl
18 alcohol foam ("PAF"). See, e.g., Horák et al., "Hydrogels in
19 Endovascular Embolization. II. Clinical Use of Spherical Particles",
20 *Biomaterials*, Vol. 7, pp. 467-470 (Nov., 1986); Rao et al., "Hydrolysed
21 Microspheres from Cross-Linked Polymethyl Methacrylate", *J.*
22 *Neuroradiol.*, Vol. 18, pp. 61-69 (1991); Latchaw et al., "Polyvinyl Foam
23 Embolization of Vascular and Neoplastic Lesions of the Head, Neck, and
24 Spine", *Radiology*, Vol. 131, pp. 669-679 (June, 1979). These materials
25 are delivered as microparticles in a carrier fluid that is injected into the
26 vascular site, a process that has proven difficult to control.

27 A further development has been the formulation of the hydrogel
28 materials into a preformed implant or plug that is installed in the vascular
29 site by means such as a microcatheter. See, e.g., U.S. Patent No.

1 5,258,042 - Mehta. These types of plugs or implants are primarily
2 designed for obstructing blood flow through a tubular vessel or the neck of
3 an aneurysm, and they are not easily adapted for precise implantation
4 within a sac-shaped vascular structure, such as an aneurysm, so as to fill
5 substantially the entire volume of the structure.

6 U.S. Patent No. 5,823,198 - Jones et al. discloses an expansible
7 PVA foam plug that is delivered to the interior of an aneurysm at the end
8 of a guidewire. The plug comprises a plurality of pellets or particles that
9 expand into an open-celled structure upon exposure to the fluids within
10 the aneurysm so as to embolize the aneurysm. The pellets are coated with
11 a blood-soluble restraining agent to maintain them in a compressed state
12 and attached to the guidewire until delivered to the aneurysm. Because
13 there is no mechanical connection between the pellets and the guidewire
14 (other than the relatively weak temporary bond provided by the
15 restraining agent); however, premature release and migration of some of
16 the pellets remains a possibility.

17 There has thus been a long-felt, but as yet unsatisfied need for an
18 aneurysm treatment device and method that can substantially fill
19 aneurysms of a large range of sizes, configurations, and neck widths with
20 a thrombogenic medium with a minimal risk of inadvertent aneurysm
21 rupture or blood vessel wall damage. There has been a further need for
22 such a method and device that also allow for the precise locational
23 deployment of the medium, while also minimizing the potential for
24 migration away from the target location. In addition, a method and
25 device meeting these criteria should also be relatively easy to use in a
26 clinical setting. Such ease of use, for example, should preferably include a
27 provision for good visualization of the device during and after
28 deployment in an aneurysm.

29

1 SUMMARY OF THE INVENTION

2 Broadly, an embolization device, according to a first aspect of the
3 present invention, comprises one or more expansible, hydrophilic
4 embolizing elements non-releasably carried on a filamentous carrier at
5 spaced intervals along the length of the carrier. In a preferred
6 embodiment, the carrier is a suitable length of very thin, highly flexible
7 filament of nickel/titanium alloy. The embolizing elements are separated
8 from each other on the carrier by radiopaque spacers in the form of highly
9 flexible microcoils made of platinum or platinum/tungsten alloy, as in the
10 thrombogenic microcoils of the prior art, as described above.

11 In a preferred embodiment, the embolizing elements are made of a
12 hydrophilic, macroporous, polymeric, hydrogel foam material, in
13 particular a swellable foam matrix formed as a macroporous solid
14 comprising a foam stabilizing agent and a polymer or copolymer of a free
15 radical polymerizable hydrophilic olefin monomer cross-linked with up to
16 about 10% by weight of a multiolefin-functional cross-linking agent. Such
17 a material is described in U.S. Patent No. 5,750,585 - Park et al., the
18 disclosure of which is incorporated herein by reference. The material
19 may be modified, or provided with additives, to make the implant visible
20 by conventional imaging techniques.

21 A second aspect of the present invention is a method for
22 embolizing a vascular site, comprising, in the preferred embodiment the
23 steps of: (a) passing a microcatheter intravascularly so that its distal end is
24 introduced into a target vascular site; (b) passing a vaso-occlusive device
25 through the microcatheter into the target vascular site so that the vaso-
26 occlusive device assumes a three-dimensional configuration that fills a
27 portion of the volume of the target vascular site; (c) providing a vascular
28 embolization device comprising at least one expansible embolizing
29 element non-releasably connected to a filamentous carrier; (d) passing the

1 embolization device through the microcatheter so that it emerges from the
2 distal end of the microcatheter into the target vascular site; and (e)
3 expanding the embolizing element or elements *in situ* substantially to fill
4 the remaining volume of the target vascular site while maintaining the
5 connection between the embolizing element or elements and the carrier.

6 Preferably, the vaso-occlusive device is of the type that is initially in
7 the form of an elongate, flexible, filamentous element for delivery through
8 the microcatheter, and that assumes a three-dimensional geometry upon
9 installation in the target vascular site. One such device is the above-
10 described GDC (U.S. Patent No. 5,122,136- Guglielmi et al., the
11 disclosure of which is incorporated herein by reference). Other such
12 devices are describe in, for example, U.S. Patents Nos. 5,766,219 -
13 Horton; 5,690,671 - McGurk et al.; and 5,911,731 - Pham et al., the
14 disclosures of which are incorporated herein by reference. Still other
15 types of vaso-occlusive devices known in the art may also perform
16 satisfactorily in this method.

17 In an alternative embodiment of the method of the present
18 invention, the method comprises the steps of: (a) deploying an
19 intravascular device to a position in a blood vessel adjacent to a target
20 vascular site; (b) providing a vascular embolization device comprising at
21 least one expansible embolizing element non-releasably connected to a
22 filamentous carrier; (c) passing a microcatheter intravascularly so that the
23 distal end of the microcatheter passes through the intravascular device
24 into the target vascular site; (d) passing the embolization device through
25 the microcatheter so that it emerges from the distal end of the
26 microcatheter into the target vascular site; and (e) expanding the
27 embolizing element or elements *in situ* substantially to fill the volume of
28 the target vascular site while maintaining the connection between the
29 embolizing element or elements and the carrier.

1 It is understood that the step of providing the embolization device
2 may follow the step of passing the microcatheter intravascularly.

3 In this alternative embodiment, the intravascular device may be of
4 the type disclosed in U.S. Patent No. 5,980,514 - Kupiecki et al., the
5 disclosure of which is incorporated herein by reference. This
6 intravascular device comprises a filamentous element that is introduced
7 by a microcatheter to the juncture of an aneurysm or the like, and that
8 then assumes the configuration of a coil adjacent the neck of the
9 aneurysm.

10 In some instances, the step of passing a vaso-occlusive device or an
11 intravascular device through the microcatheter to the target vascular site
12 may be omitted.

13 The embolization bodies or elements, in the preferred embodiment,
14 have an initial configuration in the form of small, substantially cylindrical
15 "micropellets" of small enough outside diameter to fit within the
16 microcatheter. The bodies are hydrophilically expansible into an
17 expanded configuration in which they substantially conform to and fill the
18 vascular site.

19 The present invention provides a number of significant advantages.
20 Specifically, the present invention provides an effective vascular
21 embolization device that can be deployed within a vascular site with
22 excellent locational control, and with a lower risk of vascular rupture,
23 tissue damage, or migration than with prior art devices. Furthermore, the
24 embolization device effects a conformal fit within the site that promotes
25 effective embolization, and yet its ability to be delivered to the site
26 through a microcatheter facilitates precise and highly controllable
27 deployment. In addition, the essentially filamentous initial configuration
28 of the embolization device, whereby it readily conforms to the interior
29 dimensions of the vascular site, allows it to be used effectively to embolize

1 vascular sites having a wide variety of sizes, configurations, and (in the
2 particular case of aneurysms) neck widths. These and other advantages
3 will be readily appreciated from the detailed description that follows.

4 5 BRIEF DESCRIPTION OF THE DRAWINGS

6 Figure 1 is an elevational view of a vascular embolization device in
7 accordance with a preferred embodiment of the invention;

8 Figure 2 is a cross-sectional view taken along line 2 - 2 of Figure 1;

9 Figure 3 is a cross-sectional view taken along line 3 - 3 of Figure 2;

10 Figures 4 through 7 are semischematic views showing the steps in a
11 method of embolizing a vascular site (specifically, an aneurysm) in
12 accordance with one embodiment of the embolizing method aspect of the
13 present invention;

14 Figure 8 is a detailed perspective view of mechanism by which the
15 embolization device of the present invention is preferably attached to the
16 distal end of a deployment instrument;

17 Figure 9 is a detailed perspective view, similar to that of Figure 8,
18 showing the embolization device of the present invention after it has been
19 separated from the deployment instrument;

20 Figures 10, 11, and 12 are semischematic views showing steps that,
21 in addition to those illustrated in Figures 4-7, constitute a method of
22 embolizing a vascular site in accordance with a preferred embodiment of
23 the embolizing method aspect of the present invention; and

24 Figure 13 is a semischematic view showing a step in a method of
25 embolizing a vascular site in accordance with an alternative embodiment
26 of the embolizing method aspect of the present invention.

27 28 DETAILED DESCRIPTION OF THE INVENTION

29 The Embolization Device. A vascular embolization device 10, in

1 accordance with the present invention, is shown in Figures 1, 2 and 3. In
2 the preferred embodiment, the embolization device 10 comprises a
3 plurality of embolizing bodies, each configured as a substantially
4 cylindrical "micropellet" 12, located at spaced intervals along a
5 filamentous carrier 14. The number of micropellets 12 will vary,
6 depending on the length of the carrier 14, which, turn, will depend on the
7 size of the vascular site to be embolized. For a large vascular site, for
8 example, eight to twelve micropellets may be used, although an even
9 larger number may be used if necessary. In some applications (e.g., very
10 small aneurysms), as few as one or two micropellets may be used.

11 Also carried on the carrier 14 is a plurality of highly flexible
12 microcoil spacers 16, each of which is disposed between and separates a
13 pair of micropellets 12. The carrier 14 has a distal portion on which is
14 carried a relatively long distal microcoil segment 18 that is retained in
15 place by a distal retention member 20. The carrier 14 has a proximal
16 portion on which is carried a relatively long proximal microcoil segment
17 22. The proximal end of the device 10 is terminated by a hydrogel
18 linkage element 24, to be described below. The spacers 16, the distal
19 microcoil segment 18, and the proximal microcoil segment 22 are all
20 highly flexible, and they are preferably made of platinum or
21 platinum/tungsten wire, which has the advantages of being biocompatible
22 and radiopaque. The micropellets 12 are non-releasably carried on the
23 carrier 14. They may be fixed in place on the filamentous carrier 14,
24 either mechanically or by a suitable biocompatible, water-insoluble
25 adhesive, or they may be simply strung loosely on the carrier 14 between
26 successive spacers 16.

27 The micropellets 12 are preferably formed of a biocompatible,
28 macroporous, hydrophilic hydrogel foam material, in particular a water-
29 swellable foam matrix formed as a macroporous solid comprising a foam

1 stabilizing agent and a polymer or copolymer of a free radical
2 polymerizable hydrophilic olefin monomer cross-linked with up to about
3 10% by weight of a multiolefin-functional cross-linking agent. A suitable
4 material of this type is described in U.S. Patent No. 5,570,585 - Park et
5 al., the disclosure of which is incorporated herein by reference.

6 Another suitable material for the micropellets 12 is a porous
7 hydrated polyvinyl alcohol (PVA) foam gel prepared from a polyvinyl
8 alcohol solution in a mixed solvent consisting of water and a water-
9 miscible organic solvent, as described, for example, in U.S. Patent No.
10 4,663,358 - Hyon et al., the disclosure of which is incorporated herein by
11 reference. Other suitable PVA structures are described in U.S. Patents
12 Nos. 5,823,198 - Jones et al. and 5,258,042 - Mehta, the disclosures of
13 which are incorporated herein by reference. Another suitable material is
14 a collagen foam, of the type described in U.S. Patent No. 5,456,693 -
15 Conston et al., the disclosure of which is incorporated herein by
16 reference. Still another suitable material is PHEMA, as discussed in the
17 references cited above. See, e.g., Horák et al., *supra*, and Rao et al.,
18 *supra*.

19 The preferred foam material, as described in the above-referenced
20 patent to Park et al., has a void ratio of at least about 90%, and its
21 hydrophilic properties are such that it has a water content of at least about
22 90% when fully hydrated. In the preferred embodiment, each of the
23 embolizing micropellets 12 has an initial diameter of not more than about
24 0.5 mm prior to expansion *in situ*, with an expanded diameter of at least
25 about 3 mm. To achieve such a small size, the micropellets 12 may be
26 compressed to the desired size from a significantly larger initial
27 configuration. The compression is performed by squeezing or crimping
28 the micropellets 12 in a suitable implement or fixture, and then "setting"
29 them in the compressed configuration by heating and/or drying. Each of

1 the micropellets 12 is swellable or expansible to many times (at least
2 about 25 times, preferably about 70 times, and up to about 100 times) its
3 initial (compressed) volume, primarily by the hydrophilic absorption of
4 water molecules from an aqueous solution (e.g., resident blood plasma
5 and/or injected saline solution), and secondarily by the filling of its pores
6 with blood. Also, the micropellets 12 may be coated with a water-soluble
7 coating (not shown), such as a starch, to provide a time-delayed
8 expansion. Another alternative is to coat the micropellets 12 with a
9 temperature-sensitive coating that disintegrates in response to normal
10 human body temperature. See, e.g., U.S. Patents Nos. 5,120,349 -
11 Stewart et al. and 5,129,180 - Stewart.

12 The foam material of the embolizing micropellet 12 may
13 advantageously be modified, or provided with additives, to make the
14 device 10 visible by conventional imaging techniques. For example, the
15 foam can be impregnated with a water-insoluble radiopaque material such
16 as barium sulfate, as described by Thanoo et al., "Radiopaque Hydrogel
17 Microspheres", *J. Microencapsulation*, Vol. 6, No. 2, pp. 233-244 (1989).
18 Alternatively, the hydrogel monomers can be copolymerized with
19 radiopaque materials, as described in Horák et al., "New Radiopaque
20 PolyHEMA-Based Hydrogel Particles", *J. Biomedical Materials*
21 *Research*, Vol. 34, pp. 183-188 (1997).

22 The micropellets 12 may optionally include bioactive or therapeutic
23 agents to promote thrombosis, cellular ingrowth, and/or epithelialization.
24 See, e.g., Vacanti et al., "Tissue Engineering: The Design and Fabrication
25 of Living Replacement Devices for Surgical Reconstruction and
26 Transplantation," *The Lancet* (Vol. 354, Supplement 1), pp. 32-34 (July,
27 1999); Langer, "Tissue Engineering: A New Field and Its Challenges,"
28 *Pharmaceutical Research*, Vol. 14., No. 7, pp. 840-841 (July, 1997);
29 Persidis, "Tissue Engineering," *Nature Biotechnology*, Vol. 17, pp. 508-

1 510 (May, 1999).

2 The filamentous carrier 14 is preferably a length of nickel/titanium
3 wire, such as that marketed under the trade name "Nitinol". Wire of this
4 alloy is highly flexible, and it has an excellent "elastic memory", whereby
5 it can be formed into a desired shape to which it will return when it is
6 deformed. In a preferred embodiment of the invention, the wire that
7 forms the carrier 14 has a diameter of approximately 0.04 mm, and it is
8 heat-treated to form a multi-looped structure that may assume a variety of
9 three-dimensional shapes, such as a helix, a sphere, or an ovoid (as
10 disclosed, for example, in U.S. Patent No. 5,766,219 - Horton, the
11 disclosure of which is incorporated herein by reference). Preferably, the
12 intermediate portion of the carrier 14 (i.e., the portion that includes the
13 micropellets 12) and the proximal portion (that carries the proximal
14 microcoil segment 22) are formed into loops having a diameter of
15 approximately 6 mm, while the distal portion (that carries the distal
16 microcoil segment 18) may have a somewhat greater diameter (e.g.,
17 approximately 8 -10 mm). The carrier 14 may be formed of a single wire,
18 or it may be formed of a cable or braided structure of several ultra-thin
19 wires.

20 In another embodiment, the carrier 14 may be made of a thin
21 filament of a suitable polymer, such as a PVA, that is formed in a looped
22 structure. The polymer may be impregnated with a radiopaque material
23 (e.g., barium sulfate or particles of gold, tantalum, or platinum), or it may
24 enclose a core of nickel/titanium wire. Alternatively, the carrier 14 may
25 be constructed as a "cable" of thin polymer fibers that includes fibers of an
26 expansile polymer, such as polyvinyl alcohol (PVA), at spaced intervals to
27 form the micropellets 12.

28 Still another alternative construction for the carrier 14 is a
29 continuous length of microcoil. In such an embodiment, the micropellets

1 12 would be attached at spaced intervals along the length of the carrier 14.

2 As shown in Figures 1, 8, and 9, the hydrogel linkage element 24 is
3 advantageously made of the same material as the micropellets 12.

4 Indeed, the most proximal of the micropellets 12 may function as the
5 linkage element 24. The linkage element 24 is attached to the proximal
6 end of the carrier 14 by a suitable biocompatible adhesive. The purpose
7 of the linkage element 24 is to removably attach the device 10 to a
8 deployment instrument 30 (Figures 8 and 9). The deployment instrument
9 30 comprises a length of platinum or platinum/tungsten microcoil outer
10 portion 32 with a flexible wire core 34 of the same or a similar metal. The
11 deployment instrument 30 has a distal portion 36 at which the microcoil
12 outer portion 32 has coils that are more distantly-spaced (i.e., have a
13 greater pitch).

14 As shown in Figure 8, the device 10 is initially attached to the
15 deployment instrument 30 by means of the linkage element 24.
16 Specifically, the linkage element 24 is installed, in a compressed state, so
17 that it encompasses and engages both the proximal end of the
18 embolization device 10 and the distal portion 36 of the deployment
19 instrument 30. Thus, in the compressed state, the linkage element 24
20 binds the deployment instrument 30 and the embolization device 10
21 together. As shown in Figure 9, and as will be described in detail below,
22 after the device 10 is deployed in a vascular site, the linkage element 24
23 expands greatly, thereby loosening its grip on the distal portion 36 of the
24 deployment instrument 30, and thus allowing the embolization device 10
25 to be separated from the deployment instrument 30 by pulling the latter
26 proximally out of and away from the linkage element 24.

27 The Method for Embolizing a Vascular Site. One method of
28 embolizing a vascular site using the embolization device 10 is illustrated
29 in Figures 4 through 7. First, as shown in Figure 4, a microcatheter 40 is

1 threaded intravascularly, by known methods, until its distal end is located
2 within the targeted vascular site (here, an aneurysm 42). Briefly
3 described, this threading operation is typically performed by first
4 introducing a catheter guidewire (not shown) along the desired
5 microcatheter path, and then feeding the microcatheter 40 over the
6 catheter guidewire until the microcatheter 40 is positioned adjacent the
7 distal aspect of the dome of the aneurysm, as shown in Figure 4. The
8 catheter guidewire is then removed. Then, as shown in Figures 5 and 6,
9 the embolization device 10, which is attached to the distal end of the
10 deployment instrument 30, as described above, is passed axially through
11 the microcatheter 40, using the deployment instrument 30 to push the
12 device 10 through the microcatheter 40 until the device 10 is clear from
13 the distal end of the microcatheter 40 and fully deployed within the
14 aneurysm 42 (Figure 6), filling the aneurysm from its distal aspect. The
15 deployment procedure is facilitated by the visualization of the
16 embolization device 10 that is readily accomplished due to its radiopaque
17 components, as described above.

18 The embolization bodies or micropellets 12, in their compressed
19 configuration, have a maximum outside diameter that is less than the
20 inside diameter of the microcatheter 40, so that the embolization device
21 10 can be passed through the microcatheter 40. The micropellets 12 are
22 preferably compressed and "set", as described above, before the device 10
23 is inserted into the microcatheter 40. When inserting the device 10 into
24 the microcatheter 40, a biocompatible, substantially non-aqueous fluid,
25 such as polyethylene glycol, may be injected into the microcatheter 40 to
26 prevent premature expansion of the device 10 due to hydration, and to
27 reduce friction with the interior of the microcatheter 40.

28 As shown in Figure 6, when the embolization device 10 is exposed
29 from the microcatheter 40 into the interior of the vascular site 42, the

1 pores of the embolizing bodies or micropellets 12, and of the linkage
2 element 22, begin to absorb aqueous fluid from the blood within the
3 vascular site 42 to release their "set", allowing these elements to begin
4 assuming their expanded configuration. The expansion can be enhanced
5 and accelerated by injecting saline solution through the microcatheter 40.
6 The expansion of the linkage element 24 allows the embolization device
7 10 to be separated from the deployment instrument 30, as described
8 above, and the deployment instrument 30 can then be removed. Also, the
9 elastic memory of the carrier 14 causes it to resume its original looped
10 configuration once it is released from the confines of the microcatheter
11 40. Thus, almost immediately upon its release into the vascular site
12 (aneurysm) 42, the embolization device begins to occupy a significant
13 portion of the volume of the aneurysm 42.

14 If the micropellets 12 are of a hydrophilic material, they then
15 continue to expand *in situ* due to hydrophilic hydration of the material, as
16 well as from the filling of their pores with blood. If the embolizing bodies
17 12 are of a non-hydrophilic material, their expansion is due to the latter
18 mechanism only. In either case, the result, as shown in Figure 7, is the
19 substantially complete filling of the interior of the aneurysm 42 with the
20 expanded embolizing bodies or micropellets 12, whereby a substantially
21 conformal embolizing implant 44 is formed that substantially fills the
22 interior of the aneurysm 42. The micropellets 12, being non-releasably
23 carried the carrier 14 and fixed in place thereon, stay on the carrier during
24 their expansion. Thus, the chance of a micropellet separating from the
25 carrier and migrating out of the vascular site is minimized.

26 It may be advantageous, prior to performing the procedural steps
27 described above, preliminarily to visualize the aneurysm 42, by
28 conventional means, to obtain a measurement (or at least an
29 approximation) of its volume. Then, a device 10 of the appropriate size

1 can be selected that would expand to fill the measured or estimated
2 volume.

3 A preferred method of embolizing a target vascular site using the
4 embolization device 10 will be understood with reference to Figures 10-
5 12, along with Figures 4-7 (discussed above). In this preferred
6 embodiment of the method, the passing of a microcatheter 40
7 intravascularly until its distal end is introduced into a target vascular site
8 (Figure 4) is followed by the step of passing a vaso-occlusive device 50
9 through the microcatheter 40 into the target vascular site (e.g., the
10 aneurysm 42) so that the vaso-occlusive device 50 assumes a three-
11 dimensional configuration that fills a portion of the interior volume of the
12 target vascular site 42, as shown in Figure 10. The deployed vaso-
13 occlusive device 50 forms a "cage" within the aneurysm 42 that provides
14 a matrix for improved retention of the expansible embolizing bodies or
15 micropellets 12 of the embolization device 10. The embolization device
16 10 is then passed through the microcatheter 40, as described above, and as
17 shown in Figure 11, to enter the aneurysm 42 within the voids left by the
18 vaso-occlusive device 50. Finally, the embolizing bodies or micropellets
19 12 are expanded, as described above, and as shown in Figure 12, whereby
20 a substantially conformal embolizing implant 44' is formed that
21 substantially fills the remaining interior volume of the aneurysm 42.

22 Preferably, the vaso-occlusive device 50 is of the type that is
23 initially in the form of an elongate, flexible, filamentous element for
24 delivery through the microcatheter, and that assumes a three-dimensional
25 geometry (either by elastic behavior or by shape memory) upon
26 installation in the target vascular site. Such devices are describe in, for
27 example, U.S. Patents Nos. 5,122,136 - Guglielmi et al.; 5,766,219 -
28 Horton; 5,690,671 - McGurk et al.; and 5,911,731 - Pham et al., the
29 disclosures of which are incorporated herein by reference. Still other

1 types of vaso-occlusive devices known in the art may also perform
2 satisfactorily in this method. For example, a stent-like device like that
3 shown in U.S. Patent No. 5,980,554 - Lenker et al. may be employed
4 Alternatively, the vaso-occlusive device 50 may be designed or installed
5 only to enter the space near the opening or "neck" of the aneurysm. In
6 any case, the purpose of the vaso-occlusive device 50 in this method is to
7 present a structural framework that helps retain the embolization device
8 10 in place within the target vascular site.

9 An alternative embodiment of the method of the present invention
10 will be understood with reference to Figure 13. In this alternative
11 embodiment, the method includes the preliminary step of deploying an
12 intravascular device 60 to a position in a blood vessel 62 adjacent to a
13 target vascular site 42. A microcatheter 40' is passed intravascularly so
14 that its distal end passes through the intravascular device 60 into the
15 target vascular site 42. The embolization device 10 is passed through the
16 microcatheter 40' so that it emerges from the distal end of the
17 microcatheter 40' into the target vascular site 42, and the embolizing
18 elements 12 are then expanded *in situ*, as described above, substantially to
19 fill the volume of the target vascular site 42 (as shown in Figures 7 and
20 12).

21 It is understood that the step of deploying an intravascular device
22 to a position in a blood vessel adjacent to a target vascular site would
23 include any substeps necessary for such deployment. For example, if the
24 intravascular device 60 is of the type disclosed in U.S. Patent No.
25 5,980,514 - Kupiecki et al. (the disclosure of which is incorporated herein
26 by reference), the deployment step would comprise the substeps of (i)
27 passing of a microcatheter intravascularly so that its distal end is located
28 adjacent the target vascular site; (ii) passing the intravascular device
29 through the microcatheter until it emerges from the distal end of the

1 microcatheter; and (iii) allowing the intravascular device to assume a
2 three-dimensional configuration adjacent to the target vascular site. In
3 this case, either the microcatheter used for deploying the intravascular
4 device could be removed and then another microcatheter used to install
5 the embolization device, or the intravascular deployment microcatheter
6 could be repositioned for the introduction of the embolization device.

7 In this alternative method, the intravascular device presents an
8 obstruction that at least partially blocks the juncture between the target
9 vascular site and the blood vessel (e.g., the neck of an aneurysm). Thus,
10 the intravascular device helps retain the embolization device in its proper
11 position within the target vascular site.

12 Although the device 10 has been described above for use in
13 embolizing aneurysms, other applications will readily suggest themselves.
14 For example, it can be used to treat a wide range of vascular anomalies,
15 such as arteriovenous malformations and arteriovenous fistulas. Certain
16 tumors may also be treated by the embolization of vascular spaces or
17 other soft tissue voids using the present invention.

18 While a preferred embodiment of the invention has been described
19 above, a number of variations and modifications may suggest themselves
20 to those skilled in the pertinent arts. For example, the initial shape and
21 number of embolizing bodies 12 may be varied, as well as the length of
22 the carrier 14. Furthermore, other mechanisms may be found for
23 removably attaching the embolization device 10 to the deployment wire.
24 One such alternative attachment mechanism may be a transition polymer
25 joint that loosens when heated by contact with blood or by a low-level
26 electric current. These and other variations and modifications are
27 considered within the spirit and scope of the invention, as described in the
28 claims that follow.

1 WHAT IS CLAIMED IS:

2 1. A device for embolizing a vascular site, comprising:
3 an elongate, filamentous carrier; and
4 an expansible embolizing element non-releaseably connected
5 to the carrier at a fixed location thereon.

6
7 2. The device of Claim 1, wherein the embolizing element is
8 formed of a hydrophilic hydrogen foam material.

9
10 3. The device of Claim 2, wherein the foam material includes a
11 water-swellaable foam matrix formed as a macroporous solid comprising a
12 foam stabilizing agent and a polymer or copolymer of a free radical
13 polymerizable hydrophilic olefin monomer cross-linked with up to about
14 10% by weight of a multiolefin-functional cross-linking agent.

15
16 4. The device of Claim 1, wherein the embolizing element is
17 formed of a material selected from the group consisting of polyvinyl
18 alcohol foam, collagen foam, and poly (2-hydroxyethyl methacrylate).

19
20 5. The device of Claim 1, wherein the embolizing element has an
21 initial diameter of not more than about 0.5 mm and is expansible to a
22 diameter of at least about 3.0 mm.

23
24 6. The device of Claim 1, wherein the embolizing element has a
25 predetermined initial volume and is expansible to an expanded volume
26 that is at least about 25 times its initial volume.

27
28 7. The device of Claim 1, wherein the embolizing element is a first
29 embolizing element, the device further comprising at least a second

1 expansible embolizing element mechanically connected to the carrier at a
2 fixed location thereon spaced from the first expansible embolizing
3 element.

4
5 8. The device of Claim 7, further comprising a microcoil spacer
6 located on the carrier between the first and second expansible embolizing
7 elements.

8
9 9. The device of Claim 1, wherein the carrier includes a thin,
10 flexible metal wire formed into a multi-looped configuration.

11
12 10. The device of Claim 9, wherein the wire is made of an alloy of
13 nickel and titanium that exhibits good elastic memory properties.

14
15 11. The device of Claim 1, wherein the carrier includes a thin
16 filament of polymer formed into a multi-looped configuration.

17
18 12. A method for embolizing a vascular site, comprising the steps
19 of:

20 (a) passing a microcatheter intravascularly so that its distal
21 end is in a vascular site;

22 (b) providing a vascular embolization device comprising at
23 least one highly expansible embolizing element mechanically
24 connected to a flexible filamentous carrier at a fixed location
25 thereon;

26 (c) passing the embolization device through the
27 microcatheter so that it emerges from the distal end of the
28 microcatheter into the vascular site; and

29 (d) expanding the embolizing element *in situ* substantially to

1 fill the vascular site with the at least one embolizing element and
2 the carrier, while maintaining the connection between the at least
3 one embolizing element and the carrier.
4

5 13. The method of Claim 12, wherein the step of providing a
6 vascular embolization device includes the steps of:

7 (b)(1) determining at least the approximate volume of the
8 vascular site; and

9 (b)(2) selecting a vascular embolization device sized
10 substantially to fill the entire volume of the vascular site after the
11 expanding step.
12

13 14. The method of Claim 12, wherein the expanding step includes
14 the step of passing saline solution through the microcatheter and into the
15 vascular site.
16

17 15. The method of Claim 13, wherein the step of determining at
18 least the approximate volume of the vascular site includes the step of
19 visualizing the vascular site prior to or during the step of passing the
20 microcatheter intravascularly.
21

22 16. The method of Claim 12, wherein the step of passing the
23 embolization device through the microcatheter includes the step of
24 injecting a biocompatible, substantially non-aqueous fluid through the
25 microcatheter to prevent the hydration of the at least one expansible
26 embolizing element within the microcatheter.
27

28 17. The method of Claim 16, wherein the substantially non-
29 aqueous fluid is polyethylene glycol.

1 18. A device for embolizing a vascular site, comprising:
2 an elongate, filamentous carrier formed of a flexible material
3 having an elastic memory and initially configured in a multi-loop
4 configuration; and
5 a plurality of expansible embolizing elements located at
6 spaced intervals along the length of the carrier.

7
8 19. The device of Claim 18, wherein the carrier has an
9 intermediate portion on which the expansible embolizing elements are
10 located, a proximal portion, and a distal portion.

11
12 20. The device of Claim 19, wherein the intermediate portion is
13 formed into at least one loop of approximately a first diameter, the
14 proximal portion is formed into at least one loop of approximately the
15 first diameter, and the distal portion is formed into at least one loop of
16 approximately a second diameter that is greater than the first diameter.

17
18 21. The device of Claim 19, further comprising an expansible
19 linkage element on the proximal portion.

20
21 22. The device of Claim 21, wherein the linkage element is formed
22 of the same material as are the embolizing elements.

23
24 23. The device of Claim 18, wherein the embolizing elements are
25 formed of a hydrophilic hydrogel foam material.

26
27 24. The device of Claim 23, wherein the foam material includes a
28 water-swellaable foam matrix formed as a macroporous solid comprising a
29 foam stabilizing agent and a polymer or copolymer of a free radical

1 polymerizable hydrophilic olefin monomer cross-linked with up to about
2 10% by weight of a multiolefin-functional cross-linking agent.

3

4 25. The device of Claim 18, wherein the embolizing elements are
5 formed of a material selected from the group consisting of polyvinyl
6 alcohol foam, collagen foam, and poly (2-hydroxyethyl methacrylate).

7

8 26. The device of Claim 18, wherein the embolizing elements
9 have an initial diameter of not more than about 0.5 mm and are
10 expansible to a diameter of at least about 3.0 mm.

11

12 27. The device of Claim 18, wherein the embolizing elements have
13 a predetermined initial volume and are expansible to an expanded volume
14 that is at least about 25 times their initial volume.

15

16 28. A method for embolizing a target vascular site, comprising the
17 steps of:

18 (a) passing a microcatheter intravascularly so that its distal
19 end is introduced into a target vascular site;

20 (b) passing a vaso-occlusive device through the microcatheter
21 into the target vascular site so that the vaso-occlusive device
22 assumes a three-dimensional configuration that fills a portion of the
23 volume of the target vascular site;

24 (c) providing a vascular embolization device comprising an
25 expansible embolizing element non-releasably carried on a flexible
26 filamentous carrier;

27 (d) passing the embolization device through the
28 microcatheter so that it emerges from the distal end of the
29 microcatheter into the target vascular site; and

1 (e) expanding the embolizing element *in situ* substantially to
2 fill remaining volume of the target vascular site while retaining the
3 embolizing element on the carrier.
4

5 29. The method of Claim 28, wherein the step of providing a
6 vascular embolization device includes the steps of:

7 (c)(1) determining at least the approximate volume of the
8 vascular site; and

9 (c)(2) selecting a vascular embolization device sized
10 substantially to fill the entire volume of the vascular site after the
11 expanding step.
12

13 30. The method of Claim 28, wherein the expanding step includes
14 the step of passing saline solution through the microcatheter and into the
15 vascular site.
16

17 31. The method of Claim 29, wherein the step of determining at
18 least the approximate volume of the vascular site includes the step of
19 visualizing the vascular site prior to or during the step of passing the
20 microcatheter intravascularly.
21

22 32. The method of Claim 28, wherein the step of passing the
23 embolization device through the microcatheter includes the step of
24 injecting a substantially non-aqueous fluid through the microcatheter to
25 prevent the hydration of the expansible elements within the
26 microcatheter.
27

28 33. The method of Claim 32, wherein the non-aqueous fluid is
29 polyethylene glycol.

1 34. A method of embolizing a target vascular site, comprising the
2 steps of:

3 (a) deploying an intravascular device to a position in a blood
4 vessel adjacent to a target vascular site;

5 (b) providing a vascular embolization device comprising an
6 expansible embolizing element non-releasably carried on a
7 filamentous;

8 (c) passing a microcatheter intravascularly so that the distal
9 end of the microcatheter passes through the intravascular device
10 into the target vascular site;

11 (d) passing the embolization device through the
12 microcatheter so that it emerges from the distal end of the
13 microcatheter into the target vascular site; and

14 (e) expanding the embolizing element *in situ* substantially to
15 fill the volume of the target vascular site while retaining the
16 embolizing element on the carrier.

17

18 35. The method of Claim 34, wherein the step of deploying
19 comprises the steps of:

20 (a)(1) passing a microcatheter intravascularly so that its distal
21 end is positioned in a blood vessel adjacent to a target vascular site;
22 and

23 (a)(2) passing an intravascular device through the
24 microcatheter so that the intravascular device emerges from the
25 distal end of the microcatheter and assumes a three-dimensional
26 configuration adjacent to the target vascular site.

27

28 36. The method of Claim 34, wherein the step of providing a
29 vascular embolization device includes the steps of:

1 (b)(1) determining at least the approximate volume of the
2 vascular site; and

3 (b)(2) selecting a vascular embolization device sized
4 substantially to fill the entire volume of the vascular site after the
5 expanding step.

6

7 37. The method of Claim 34, wherein the expanding step includes
8 the step of passing saline solution through the microcatheter and into the
9 vascular site.

10

11 38. The method of Claim 36, wherein the step of determining at
12 least the approximate volume of the vascular site includes the step of
13 visualizing the vascular site prior to or during the step of passing the
14 microcatheter intravascularly.

15

16 39. The method of Claim 34, wherein the step of passing the
17 embolization device through the microcatheter includes the step of
18 injecting a substantially non-aqueous fluid through the microcatheter to
19 prevent the hydration of the expansible elements within the
20 microcatheter.

21

22 40. The method of Claim 39, wherein the non-aqueous fluid is
23 polyethylene glycol.

FIG. 1

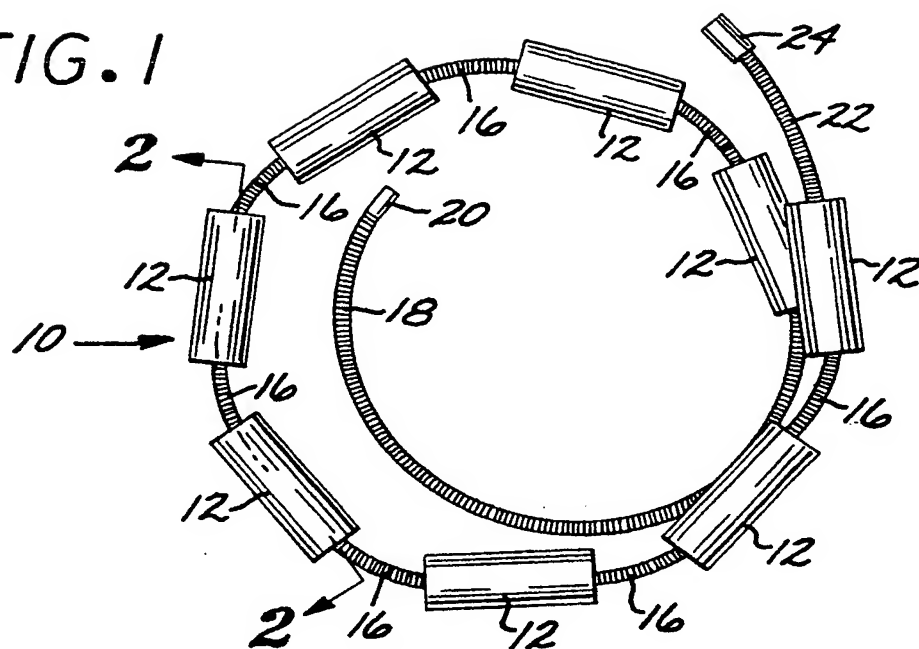


FIG. 2

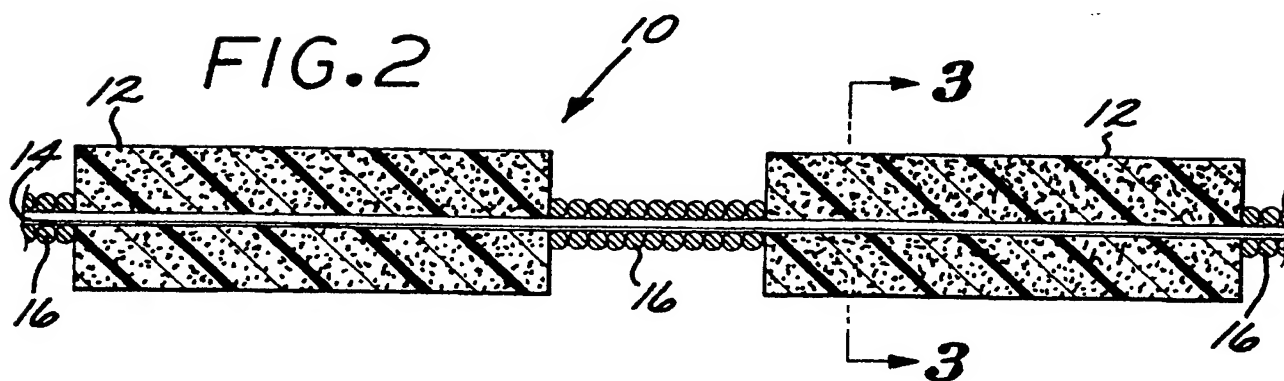


FIG. 3

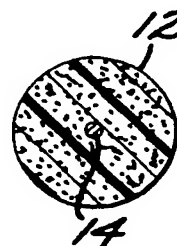


FIG. 4

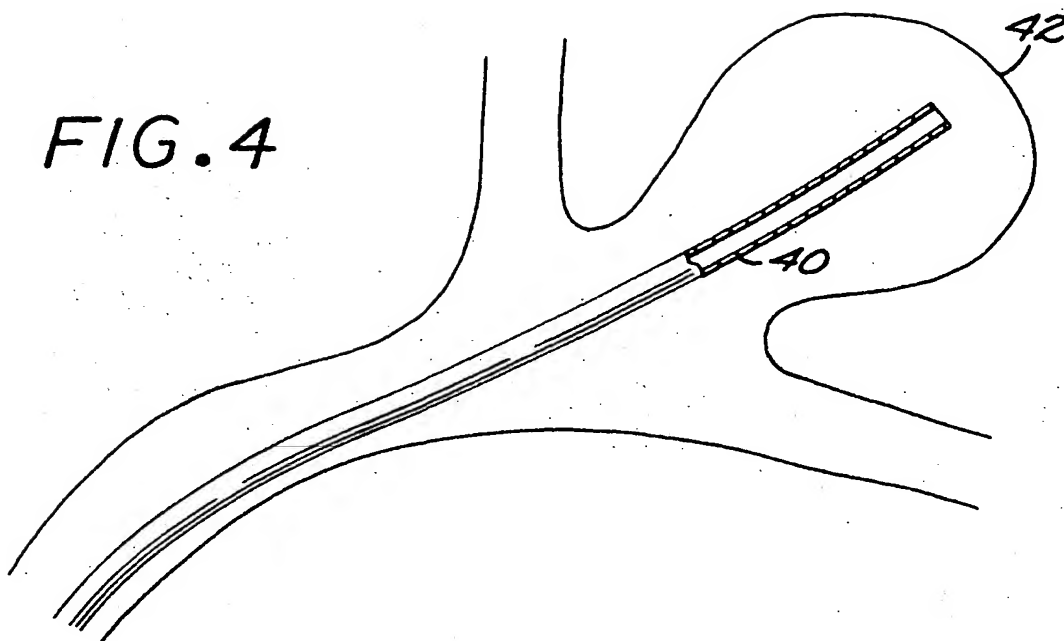


FIG. 5

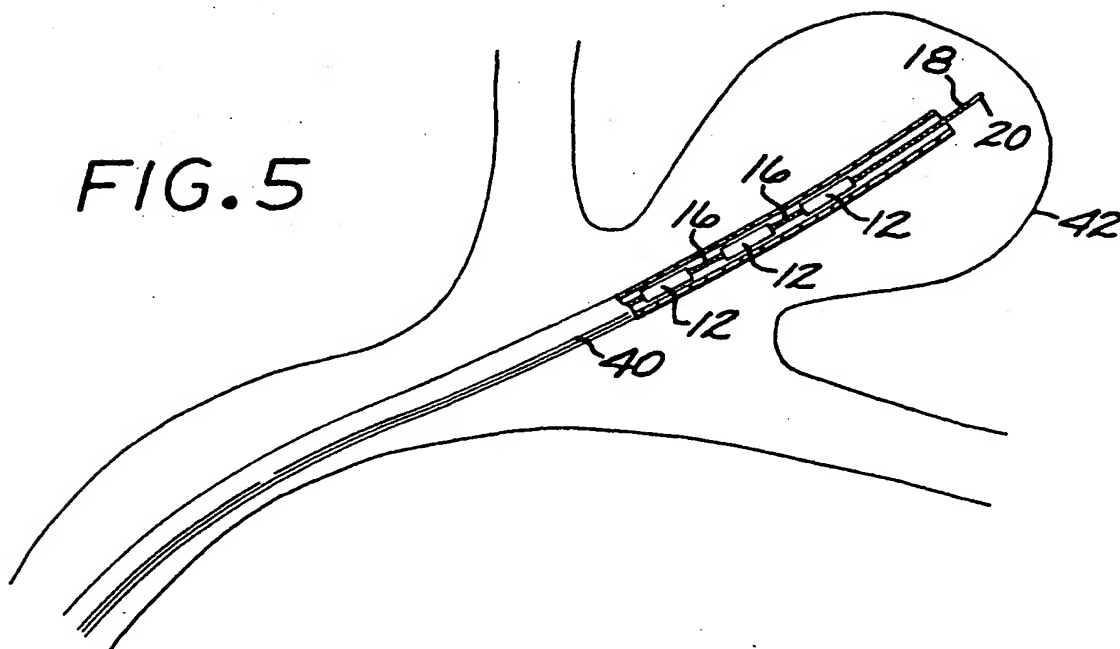


FIG. 6

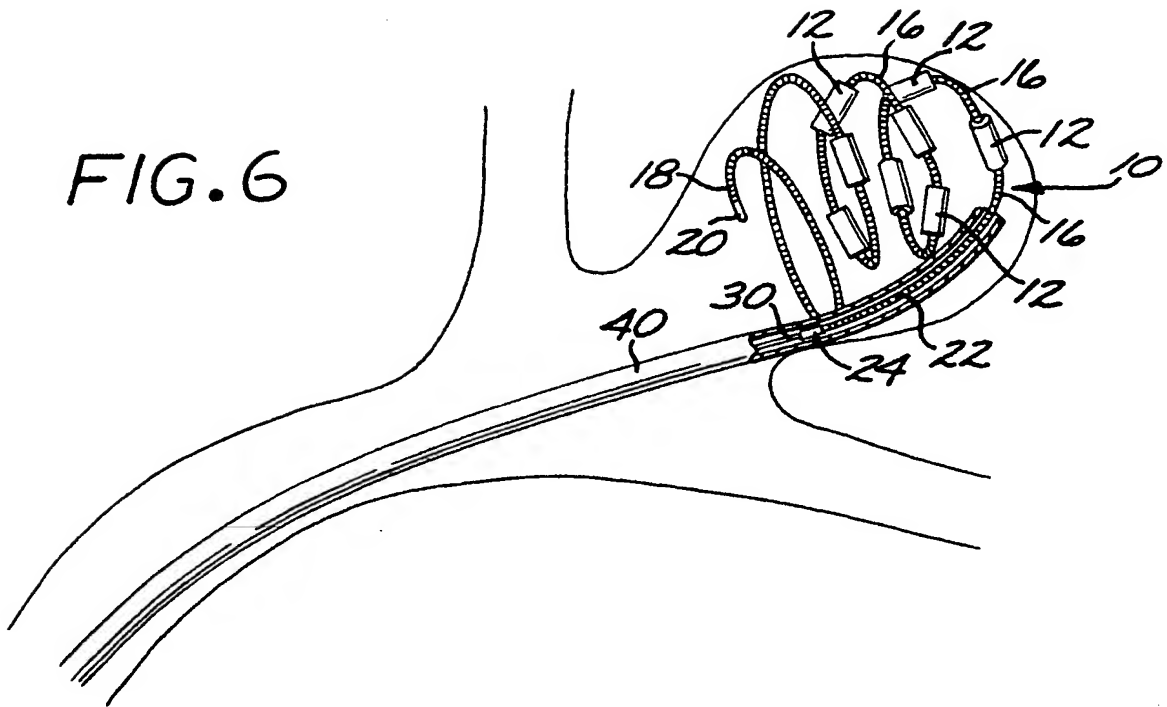
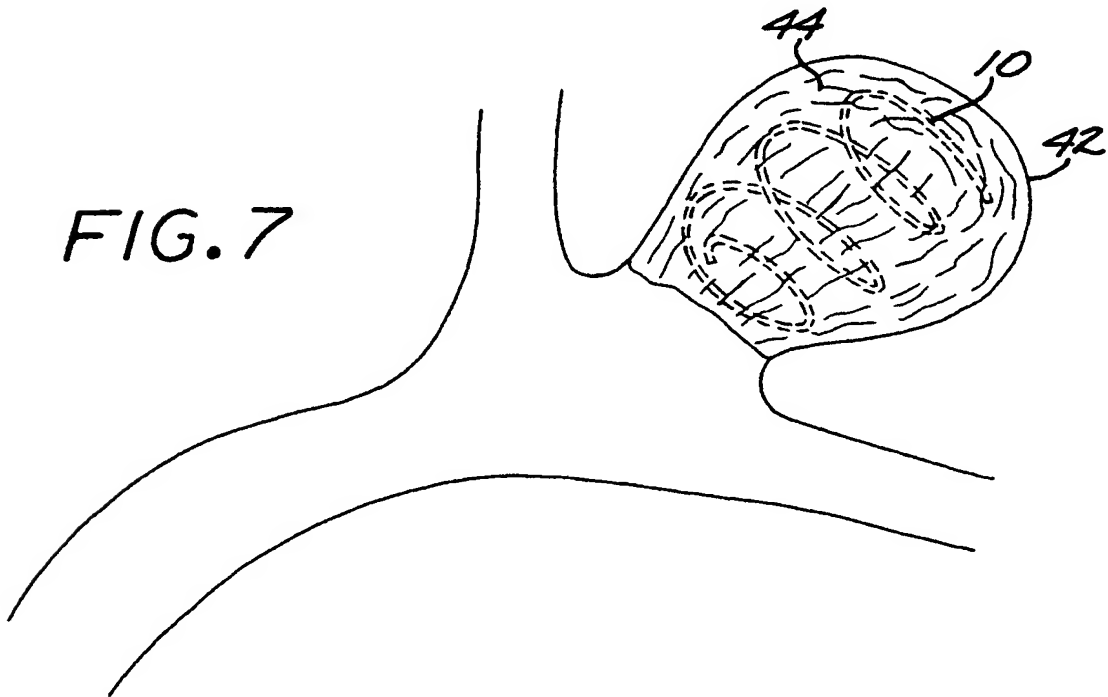


FIG. 7



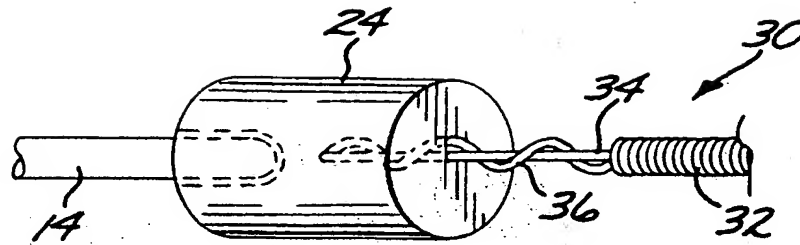


FIG. 8

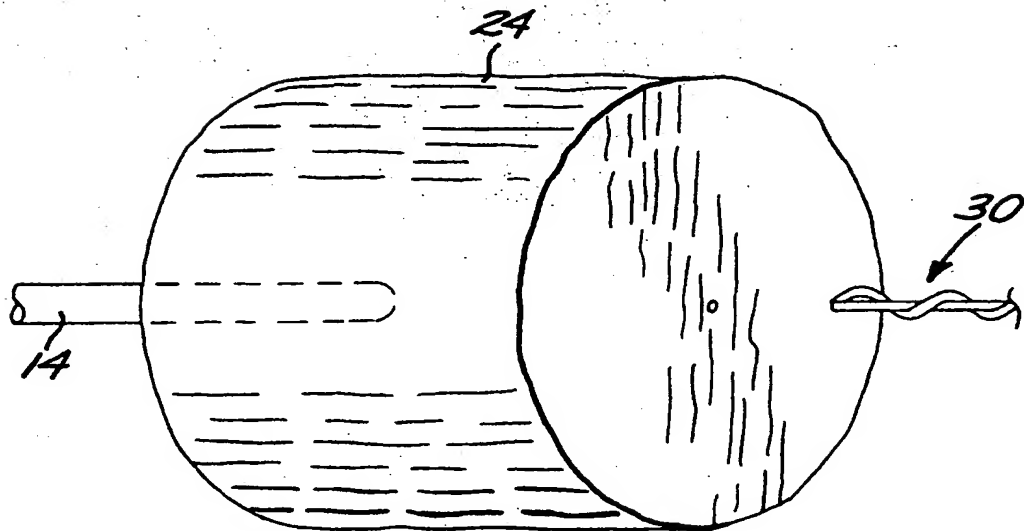


FIG. 9

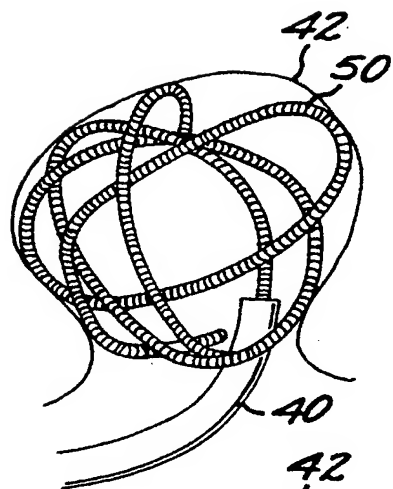


FIG. 10

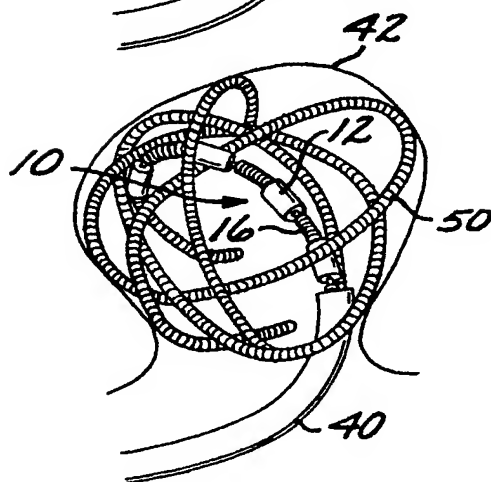


FIG. 11

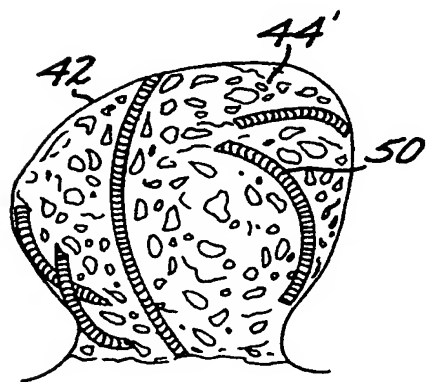


FIG. 12

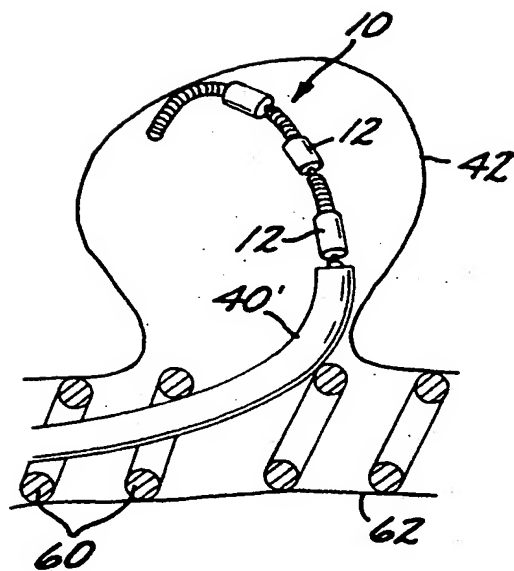


FIG. 13

INTERNATIONAL SEARCH REPORT

Int. Appl. No.
PCT/US 00/26926

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B17/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 823 198 A (JONES ET AL.) 20 October 1998 (1998-10-20) column 8, line 37 - line 56; claims 7,9; figures 6A,6B	1,5,18, 26
A	US 5 750 585 A (PARK ET AL.) 12 May 1998 (1998-05-12) column 2, line 44 - line 56	2-4, 23-25
A	US 5 582 619 A (KEN) 10 December 1996 (1996-12-10) column 6, line 31 - line 48; figures 10A-10D	1,18
A	US 5 766 219 A (HORTON) 16 June 1998 (1998-06-16) column 4, line 21 - line 44; figure 6D	4,9-11
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *G* document member of the same patent family

Date of the actual completion of the international search

4 January 2001

Date of mailing of the international search report

23/01/2001

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INTERNATIONAL SEARCH REPORT

In International Application No
PCT/US 00/26926

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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